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Soil biotreatment effectiveness for reducing global warming potential from main polluting tillage operations in life cycle assessment phase

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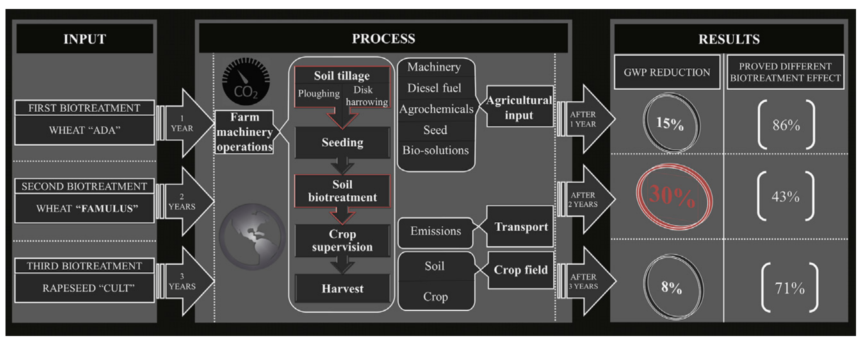
HIGHLIGHTS

- Discovered innovative biotreatment effect for HTA, GWP, EWC reduction from soil tilling in LCA phase
- Established HTA and EWC decrease with corresponding decrease of GWP.
- Identified CO_2 eq reduction from soil tilling till 30% after third soil biotreatment
- Proved GWP reducing in 86% of bio-solutions after first biotreatment

GRAPHICAL ABSTRACT



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ABSTRACT

In order to reduce global warming potential (GWP) due to anthropogenic and natural factors in the cultivation of winter wheat and rapeseed, proved effectiveness of soil biotreatment with different composition of bio-solutions. It was reduced greenhouse gases (GHG) through life cycle impact categories from the main polluting agricultural operations on deeply lukewarm soaked soil. According to the impact diapason evaluated the main indicators such as human toxicity air (HTA), ecotoxicity water chronic (EWC), global warming potential, ecotoxicity water acute (EWA), ozone formation (OF), human toxicity water (HTW), ecotoxicity soil chronic (ESC), human toxicity soil (HTS), terrestrial eutrophication (TE), acidification (A). Assessed researches for three seasons which carried out in production experimental areas. It was appreciated in interrelated stages according to LST EN ISO 14040:2007 standard. Mass balance for one functional unit (FU) was tonne of wheat and rapeseed. SimaPro 8.05 life cycle assessment (LCA) Software was used for comparing soil biotreatment efectiveness using different bio-solutions and its mixes with control. The aim of the assessment – to prove the soil biotreatment effectiveness

Abbreviations: BT1, biotreatment 1; BT2, biotreatment 2; BT3, biotreatment 3; BT4, biotreatment 4; C, control; CH_4, methane; CLCD, Chinese Life Cycle Database; CO_2, carbon dioxide; CR, crop rotation; CT, conventional tillage; DP, deep tillage; EMs, effective microorganisms; EU, European Union; EWC, ecotoxicity water chronic (m^3); FAO, Food and Agriculture Organization; FU, functional unit; GHG, greenhouse gas; GPRS, general packet radio service; GWP, global warming potential; HFCs, hydrofluorocarbons; HSD, *Tukey's* honestly significant difference; HTA, Human toxicity air (person); IPCC, intergovernmental panel on climate change; IRU, International Road Transport Union; ISO/IEC, International Organization for Standardization and the International Electrotechnical Commission; JPL, Jet Propulsion Laboratory; K, potassium (K_2O); LCA, life cycle assessment; Mn, manganese; MSs, member states; N, nitrogen; NASA, National Aeronautics and Space Administration; NE, natural energy; N_2O, nitrous oxide; NT, No–tillage system; PFCs, perfluorocarbons; T, total; SF_6, sulfur hexafluoride; NF_3, nitrogen trifluoride; TAE, trend in agricultural engineering; P, phosphorus (P (P_2O_5)); RT, conservation or reduced tillage; SC1, first (control) scenario; SC2, second scenario (using BT1 biopreparation); SC3, third scenario (using BT2 biopreparation); SC4, fourth scenario (using BT3 biopreparation); SC5, fifth scenario (using BT4 biopreparation); SC6, sixth scenario (using BT1 and BT2 biopreparation); SC7, seventh scenario (using BT1 and BT3 biopreparation); SC8, eighth scenario (using BT1 and BT4 biopreparation); SP, shallow tillage; UNFCCC, United Nations Framework Convention on Climate Change; USA, United States of America; US EPA, United States Environmental Protection Agency.

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Tillage
CO_2

for reducing main life cycle indicators from tillage operations. It was identificated that phase of field operation is one of the main factor to the global impact. Disc harrowing consists approximately 26%, ploughing – 40% of all operations. Identified effectiveness of soil biotreatment, wheat and rapeseed rotation for reduction of global warming potential. Discovered reduction interdependencies of main life cycle assessement impact categories. The largest CO_2 eq reducing established from primary – disc harrowing 12–15 cm and secondary - ploughing 23–25 cm soil tillage. It was fixed till approximately 15% in mixed bacterial and non-bacterial bio-solution after first soil biotreatment. Till approximately 8% CO_2 eq reduction was in mixed bio–solutions after second biotreatment. The percentage highest soil biotreatment effectiveness till approximately 30% assessed after third biotreatment compared to usual technology. Soil biotreatment effectiveness in reducing green house gases (GHG) proved first year in 86%, second year in 43%, and third year in 71% of all used bio–solutions.

1. Introduction

1.1. Global warming potential assessment from an agricultural perspective

By using millions of individual atmospheric CO_2 measurements from the grading spectrometer onboard the National Aeronautics and Space Administration (NASA) Orbiting Carbon Observatory–2 satellite, different CO_2 concentration maps were modelized, which established that atmospheric CO_2 concentrations increased by >40% over the last two centuries to >400 ppm.

Understanding the carbon cycle is important for developing strategies to reduce CO_2. In 2016, U.S. greenhouse gas emissions totalled 6511 million metric tons of CO_2 eq, or 5795 million metric tons of CO_2 eq, after accounting for sequestration from the land sector. Emissions decreased from 2015 to 2016 by 2.5% (after accounting for sequestration from the land sector).

Global greenhouse gas emissions can also be broken down by the economic activities that lead to their production. Agriculture, Forestry, and Other Land Use (24% of global greenhouse gas emissions): greenhouse gas emissions from this sector mostly come from agriculture (cultivation of crops and livestock) and deforestation. This estimate does not include the CO_2 that ecosystems remove from the atmosphere by sequestering carbon in biomass, dead organic matter, and soils, which offset approximately 20% of the emissions from this sector.

The top greenhouse gas emitters (European Union (EU), China, United States (US)) contribute more than half of the total global emissions, while the bottom 100 countries only account for 3.5% of the total. Collectively, the top 10 emitters account for nearly three-quarters of the global emissions. The world cannot successfully tackle the challenge of climate change without significant action from these countries (FAO, 2016).

1.2. Comparative life cycle assessment in winter plant from an environmental aspect

Due to the growing demand for global production and grain yields, the main domains for the oilseed crop are determined based on the potential life cycle of rapeseed and the main source of food (e.g., wheat, which accounts for 70–90% of the total caloric intake and 66–90% of the protein intake), which may impact many environmental categories (Houshyar and Grundmann, 2017; Kole, 2006).

The emission of greenhouse gases via the wheat cropping system is extracted from the total energy consumption (in MJ ha^{-1}) by taking into account the quantities of each input: fertilizer, plant protection products, labour force, fuel, water and seeds via equivalent inputs (machinery (kg): 62.7; diesel (L): 56.3; liquid chemical (L): 102; granular chemical (kg): 120; human labour employment (h): 1.96; nitrogen (kg): 78.1; phosphorus (kg): 12.44; potassium (kg): 11.15; water (m^3): 0.63; wheat grain (kg): 14.7; and wheat straw (kg): 12.5) and corresponding CO_2 eq emissions in agricultural production (i.e., emissions factors) (CLCD v0.7; Ecoinvent v2.2; Wang et al., 2016; Chaudhary et al., 2006; Mani et al., 2007). The estimated total energy consumption ranges from 26,600 to 33,500 MJ ha^{-1} (from fertilizers, diesel fuel, and water and seed inputs) per 5700–6500 kg ha^{-1}, respectively (Houshyar and Grundmann, 2017; Fernández-Tirado et al., 2016). By comparing traditional and organic wheat production systems using 1 kg of cereals as the FU, there is no significant difference between global warming rates and the cumulative energy demand, but there are significant differences in soil acidification and eutrophication. Regarding the traditional farming yield (8.5 t ha^{-1} at 15% moisture versus 4.5 t ha^{-1} for organic wheat), organic winter wheat can produce an equivalent yield. Otherwise, the impact of several exposure categories is greater than that of conventional winter wheat (Van Stappen et al., 2015).

The GWP for oilseed and rapeseed cultivation and harvesting could vary from approximately 600 ± 15 kg to 1900 ± 57 kg of CO_2 eq depending on different systems. The main factors forming GWP are diesel used for machinery (approximately 150 ± 5 kg to 170 ± 6 kg CO_2 eq) and the manufacturing and maintenance of machinery (approximately 1200 ± 11 kg to 1400 ± 30 kg (FU: ha/year)) (Stephenson et al., 2008; Kaltschmitt et al., 1997; Mortimer and Elsayed, 2006). It has been found that it is possible to reduce GHGs by 29% for the rapeseed system (Thamsiriroj and Murphy, 2009). In addition, according to the LCA results, the GWP amounts to 1181.6 kg CO_2 eq Mg^{-1} (when the functional unit is one Mg of rapeseed production) (Mousavi-Avval et al., 2017).

The use of diesel for cultivating machinery is less affected by soil structure (Stephenson et al., 2008). Shallow cultivation requires approximately 14 L of deep tillage (~23 L per hectare) (Stephenson et al., 2008; Nix, 2007; Gabain, 2007). It is difficult to take into account the actual rotational change of plants in the context of nutrient changes, the reduction of agricultural needs, and crop rotation and composition, but extending the limits of the research system and taking into account all crop rotations in the energy field and local agricultural management practices increase the potential for greenhouse gas reduction (Peter et al., 2017). It is beneficial to evaluate the most pollutant phase during the life cycle of an environmentally friendly crop since crop rotation (wheat–rapeseed) produces specific results (Mousavi-Avval et al., 2017).

1.2.1. Global warming potential from agricultural machinery in soil tilling

One of the main contributors to total energy inputs is the use of fertilizers, field operations (diesel fuel) and the system that makes the highest machinery and diesel fuel inputs are conventional cultivations (Mousavi-Avval et al., 2017; Bartzas et al., 2017). Also, the use of fertilizers from farm to farm depends on soil treatment and crop rotation too (Mousavi-Avval et al., 2017; Bartzas et al., 2017). By changing the energy consumption, it is also possible to change the environmental effectiveness of reducing CO_2 emissions due to anthropogenic activity (Elhami et al., 2016; Bartzas et al., 2017). Agricultural outputs per ton of product (wheat, rapeseed) or per hectare (Weinheimer et al., 2010) are estimated by farm management indicator.

Reducing environmental pollution and protecting ecosystems from the effects of intensive chemical agents may lead to the use of alternatives to intensive farming systems, during which the unused nutrients in the poppy period are switched to a biochemical chain which, in the further process of biological transformation, becomes plant nutrition products, including the use of mechanical irrigation systems, precise

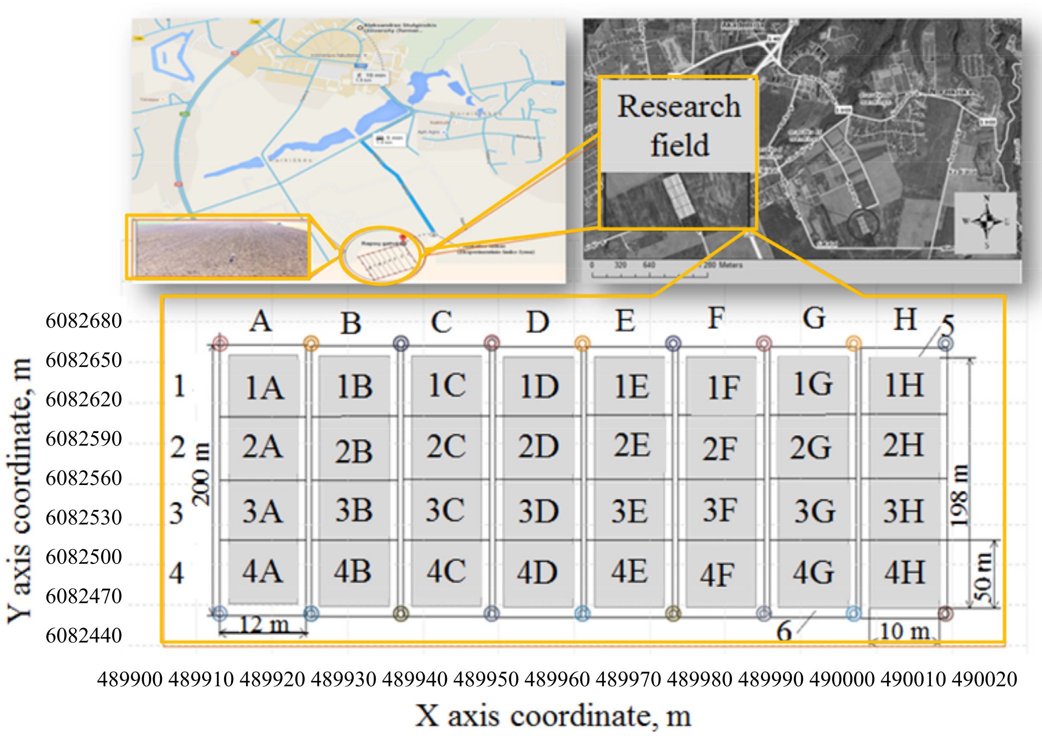

Fig. 2.1. Location and design of experimental research.

fertilization management (Arlauskienė and Maikštėnienė, 2007; Mohammadi et al., 2014). Crop production strategies need to be developed by optimizing the costs (space, time and quantities) that can increase yields in terms of resources, environmental and economic performance, and therefore LCA needs sustainability decisions in the context of the multiple exposure category (Todorović et al., 2018). The LCA methodology for this assessment allows for better business development decisions and conclusions, as it can be classified environmental impacts and ecological aspects of global warming, human health in many categories.

The LCA result usually has hundreds of different emissions and resource extraction parameters. Estimated CO_2 emissions are the most representative and most relevant greenhouse gases according to GWP100 (Ingrao et al., 2018) and attributing the results of CO_2 emissions to the corresponding global warming exposure category (Bos and Meesters, 2008).

Soil tillage is one of the most important, expensive and fuel–consuming technological processes (Naujokienė et al., 2018; Notarnicola et al., 2017; Robertson et al., 2000). Air pollution in the crop sector has been reduced by using a new biotechnology. This technology (which uses biomaterials according to a unique targeted methodology) replaces soil properties and reduces fuel consumption in agricultural operations, which reduces environmental pollution (Naujokienė et al., 2018). These specialized biomaterials result in crop breaking, which improves essential soil properties. Changes in soil properties facilitate the work of cultivating machines and their working parts, which reduces fuel consumption for cultivating soil (Zhang et al., 2011; Stephenson et al., 2008). Reducing fuel consumption, as one of the most important and energy–intensive agricultural operations in agriculture, reduces the cost of feed production and, at the same time, preserves the environment.

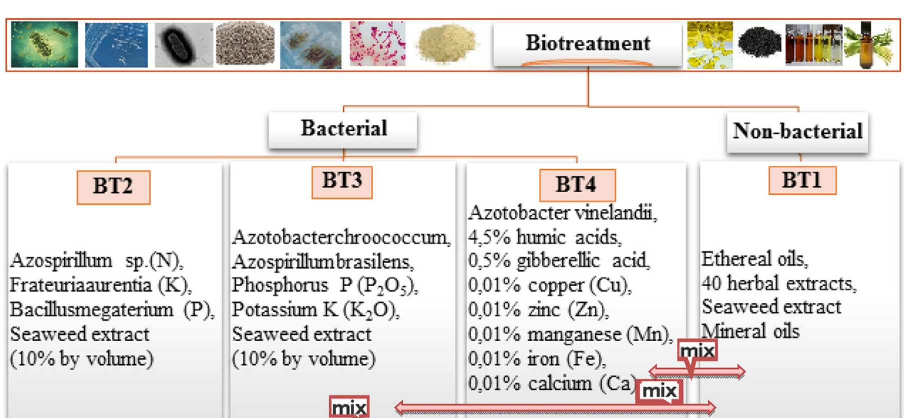

Fig. 2.2. Analysed consistency crop cultivation process chain (estimated influenced stages marked red color).

Although there are another version of soil tillage practices and other soil tillage techniques such as minimum, straw or direct sowing. No–tillage and reduced-tillage systems can achieve better environmental performance than conventional tillage systems and have the lowest impact on the GWP and other environmental categories (Houshyar and Grundmann, 2017; Fallahpour et al., 2012; Lovarelli et al., 2017).

It is possible to determine the effectiveness of different biological measures for different purposes. The results of nanoparticles absorbed by plants and cultivation in Cd-contaminated sediments amended with S-nZVI at 100, 500, and 1000 mg kg^{-1} identified that Cd content in cell wall of plants are reducing and concentration in cell organelle and soluble fractions are increasing. So it is very important to choose appropriate feedstocks, suitable compositions for best optimization of production conditions (Gong et al., 2017; Huang et al., 2018). Various scientific studies have indicated that GHG emissions depend on climate and soil characteristics and different effects and working conditions (Peter et al., 2017). Therefore, in agricultural practice, biotechnology could be used for the biological protection of plants (e.g., reducing the spread of pathogens and pests) to increase the productivity of crops, improve the microbiological state of soils, change the physical or chemical properties of soils and regulate not only the effects on plants but also soil microbiocenosis (Zhang et al., 2011; Epron et al., 2016; Tullberg et al., 2018). By other researches proved, that biotic remediation with RNZVI could increase the OC bioavailability through changing themicrobial community composition (Xue et al., 2018). Also the modification of mineral fertilizers with nutrients (Nitrogen (N), Phosphorus (P), Potassium (K)), biotreatment and organic waste can maintain or increase the organic carbon content of soil, increase porosity and reduce the energy consumption via soil cultivation and the effects of global warming on synthetic fertilizers (Švedas et al., 2001; Cesevičius and Janušauskaitė, 2006; Mažvila et al., 2006). Therefore, this work is used to assess the dependence of energy and environmental efficiency on the technological processes of soil tillage using different biotreatment by controlling diesel fuel inputs into the conventional system (Naujokienė et al., 2018). That is why the aim of this work – to prove the soil biotreatment effectiveness for reducing global warming potential from main tillage operations in life cycle assessment phase.

2. Study area and methodology

It was estimated the total reduction of GWP due to field operations and the naturally occurring soil, depending on the cultivated plants and soil biotreatment (guided by the carbon model combined with the Intergovernmental Panel for Climate Change (IPCC) and Tier II methodology for soil emissions (Goglio et al., 2018).

Analysed GWP in the middle of Lithuania meteorological conditions. Frost line 2015–23 cm^{-1}, 2016–46 cm^{-1}; Annual precipitation 2015–55 cm^{-1}, 2016–84 cm^{-1}; Average temperature 2015–8.7 °C, 2016–7.7 °C; Average snow depth (the biggest in winter) 2015–4 cm^{-1}, 2016–13 cm^{-1}. Analysed tilled area (2015–2017) in Aleksandras Stulginskis University experimental station (54°534 N + 23°50′ E), southwest side of Lithuanian Kaunas city near Nemunas river, relief – a slightly wavy plain, deeply lukewarm soaked soil (Endohypogleyic–Eutric Planosol – PLe–gln–w), pH – 6.5–7.2, total

Table 2.1
Analysed consistency crop cultivation process chain (estimated influenced stages marked red color).

Operations	C	BT1	BT2	BT3	BT4	BT1+BT2	BT1+BT3	BT1+BT4
Autumn								
Winter wheat „Ada“ (2015)/ „Famulus“ (2016)/rapeseed „Cult“ (2017) seeding	+	+	+	+	+	+	+	+
Herbicide spraying 2.0 Lha^{-1}	+	+	+	+	+	+	+	+
Spring								
Fertilization ammonium nitrate (N_{51}) 200 kg ha^{-1}	+	+	+	+	+	+	+	+
Fungicide 0.81 L ha^{-1} and growth regulator 1.2 Lha^{-1} spraying	+	+	+	+	+	+	+	+
Spraying	+	+	+	+	+	+	+	+
Water	+	+	+	+	+	+	+	+
Biotreatment 1	–	+	–	–	–	–	–	–
Biotreatment 2			+	–	–	–	–	–
Biotreatment 3	–	–	–	+	–	–	–	–
Biotreatment 4	–	–	–	–	+	–	–	–
1+2 Biotreatment	–	–	–	–	–	+	–	–
1+3 Biotreatment	–	–	–	–	–	–	+	–
1+4 Biotreatment	–	–	–	–	–	–	–	+
Summer								
Additional fertilization ammonium nitrate (N_{68}) 140 kg ha^{-1}	+	+	+	+	+	+	+	+
Fungicide 0.3 Lha^{-1} and growth regulator 0.3 Lha^{-1} spraying	+	+	+	+	+	+	+	+
Additional fertilization urea (N_{46}) 10 Lha^{-1} and fungicide 1.75 Lha^{-1} spraying	+	+	+	+	+	+	+	+
Additional fertilization ammonium nitrate (N_{68}) 80 kg ha^{-1}	+	+	+	+	+	+	+	+
Harvest	+	+	+	+	+	+	+	+
Disc harrowing	+	+	+	+	+	+	+	+
Ploughing	+	+	+	+	+	+	+	+

Table 2.2
Harvest change for the FU (functional unit).

	Harvest, t ha^{-1}	Area for FU, m^2 t^{-1} wheat	Harvest, t ha^{-1}	Area for FU, m^2 t^{-1} wheat	Harvest, t ha^{-1}	Area for FU, m^2 t^{-1} rapeseed
SC1	6.81	352	7.6	316	4.5	533
SC2	6.24	385	6.8	353	5.2	462
SC3	7.18	334	7	343	4.4	545
SC4	7.6	316	6.3	381	6.28	382
SC5	7.44	323	7.6	316	4	600
SC6	7.38	325	7.6	316	6.03	398
SC7	8.02	299	7.4	324	4.5	533
SC8	7.61	315	7.9	304	4.8	500

nitrogen – 1.47–1.59%, humus – 2.2–3.0%, mobile phosphorus – 173–235 mg kg^{-1}, mobile potassium – 115–189 mg kg^{-1}, mobile sulfur – 5.6–26.4 mg kg^{-1} (Naujokienė et al., 2018). Using the General Packet Radio Service (GPRS) Global System for Mobile Communications (GSM) network fixed experimental field tag coordinates 54.878337, 23.842755 (GT–19505) (Rape street 53,367, Ringaudai parish, Jotainiai) (Fig. 2.1).

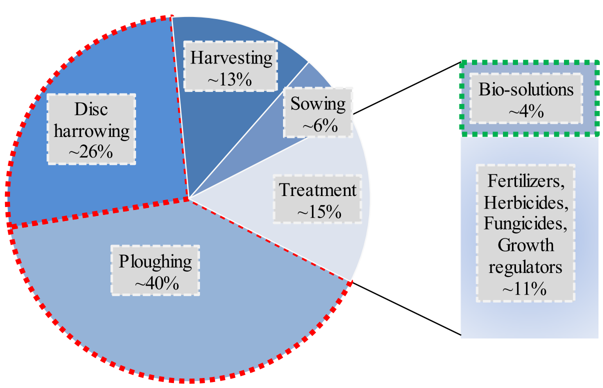

Fig. 3.1. Average percentage of the farm machinery operations for concrete in the total GWP on a varied interval range. The largest researched results are noted with red-coloured dashes; additional bio-measurements are noted with green-coloured dashes.

GWP from soil tillage were analysed consistently for three years in process chain. It was added new non–chemical spraying stage, where soil was treated with different biosolutions using Amazone UF–901 (Fig. 2.2/Table 2.1). It was highlighted main LCA impact categories and its reduction dependence on biotreatment.

2.1. Evaluation of soil biotreatment effectiveness for reducing environmental impact from agricultural machinery during the life cycle assessment phase

The conventional tillage system with the greatest pollution and experimental studies on the environmental impact of soil tillage technology were analysed. Such as shallow scrubbing via 12–15 cm depth spray (SP) and deep ploughing at a 23–25 cm depth (DP) using tractor ZETOR 10540. The amount of data required for each calculation depends on the methods used in the calculation programme, the processes and sources calculated amount of used GHGs. The comprehensive harvest and energy input data during the LCA phase were integrated and recalculated using the tier methodology. Given assessment methodologies had the same level of complexity as the IPCC guidelines, which linked different assessment methodologies.

SimaPro is used in many LCA practices around the world as a decision support tool (Herrmann and Moltesen, 2015). The environmental impacts of wheat and rapeseed cultivation under different non–chemical soil treatments were evaluated using one of the main calculator. SimaPro 8.0.5Sc including the material databases of ETHESU 96, Buwal 250, Idemat 2001, Franklin US LCI and the industrial datasets of APME, NIDI, IISI, and Pre Consultants, indicator calculation pathways

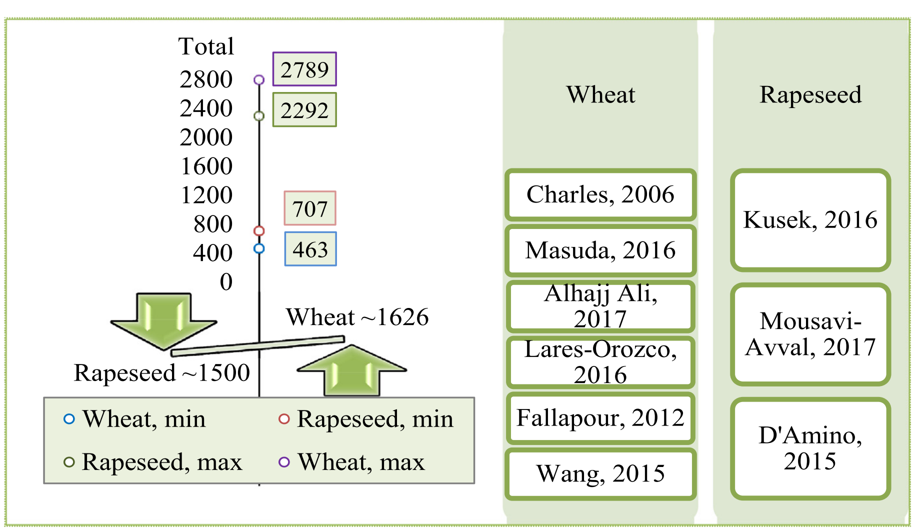

Fig. 3.2. Total GWP variation in the interval range.

Table 3.1
Descending variations in the LCA impact categories depending on soil biotreatment and crop rotation (2015: wheat "Ada"; 2016: wheat "Famulus"; 2017: rapeseed "Cult"). The red shadow marks the impact categories with the largest data values.

Impact category	Unit	Total (biopreparations spraying+disc harrowing+ploughing)								
Variations			SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8
		Human toxicity air, person								
		2015	293894.4	320863.7	279842.5	264868.3	270908.5	270532.4	250587.3	262039.0
		2016	268703.5	295532.4	288322.6	314531.1	270908.5	262334.4	267293.2	245661.6
1 **Human toxicity air**	**person**	**2017**	445040.1	388414.0	466404.2	314531.1	507953.4	327918.0	442704.3	409436.0
		Ecotoxicity water chronic, m^3								
		2015	4931.3	5400.5	4692.6	4430.4	4539.4	4557.2	4201.2	4416.2
		2016	4508.7	4974.2	4834.8	5261.1	4539.4	4419.1	4481.3	4140.1
2 **Ecotoxicity water chronic**	**m^3**	**2017**	7467.5	6537.5	7820.9	5261.1	8511.4	5523.9	7422.1	6900.2
		Global warming 100a, kg CO_2 eq								
		2015	**3235.1**	**3538.3**	**3069.7**	**2895.1**	**2968.6**	**2986.9**	**2748.0**	**2895.0**
		2016	**2957.8**	**3259.0**	**3162.7**	**3437.9**	**2968.6**	**2896.4**	**2931.2**	**2714.1**
3 **Global warming 100a**	**kg CO_2 eq**	**2017**	**4898.8**	**4283.3**	**5116.1**	**3437.9**	**5566.1**	**3620.5**	**4854.8**	**4523.4**
		Ecotoxicity water acute, m^3								
		2015	846.9	927.6	805.8	760.7	779.5	782.8	721.4	758.6
		2016	774.3	854.4	830.2	903.3	779.5	759.1	769.5	711.2
4 Ecotoxicity water acute	m^3	2017	1282.4	1122.9	1343.0	903.3	1461.5	948.9	1274.5	1185.3
		Ozone formation, m^2.ppm.h								
		2015	171.7	188.0	163.4	154.3	158.1	158.6	146.3	153.7
		2016	157.0	173.2	168.4	183.2	158.1	153.8	156.0	144.1
5 Ozone formation	m^2.ppm.h	2017	260.0	227.6	272.3	183.2	296.4	192.3	258.4	240.2
		Human toxicity water, m^3								
		2015	126.6	138.6	120.5	113.8	116.6	117.0	107.9	113.3
		2016	115.8	127.7	124.1	135.1	116.6	113.4	115.1	106.2
6 Human toxicity water	m^3	2017	191.7	167.8	200.8	135.1	218.6	141.8	190.6	177.1
		Ecotoxicity soil chronic, m^3								
		2015	19.4	21.3	18.5	17.5	17.9	17.9	16.6	17.4
		2016	17.8	19.6	19.1	20.8	17.9	17.4	17.7	16.3
7 Ecotoxicity soil chronic	m^3	2017	29.4	25.7	30.8	20.8	33.6	21.7	29.3	27.1
		Human toxicity soil, m^3								
		2015	2.5	2.8	2.4	2.3	2.3	2.3	2.2	2.3
		2016	2.3	2.6	2.5	2.7	2.3	2.3	2.3	2.1
8 Human toxicity soil	m^3	2017	3.9	3.4	4.0	2.7	4.4	2.8	3.8	3.6
		Terrestrial eutrophication, m^3								
		2015	2.1	2.3	2.0	1.9	2.0	2.0	1.8	1.9
		2016	2.0	2.2	2.1	2.3	2.0	1.9	1.9	1.8
9 Terrestrial eutrophication	m^2	2017	3.2	2.8	3.4	2.3	3.7	2.4	3.2	3.0
		Acidification, m^3								
		2015	1.0	1.1	1.0	0.9	0.9	0.9	0.9	0.9
		2016	0.9	1.0	1.0	1.1	0.9	0.9	0.9	0.9
10 Acidification	m^2	2017	1.5	1.3	1.6	1.1	1.8	1.1	1.5	1.4

(tier; 1,2 and 3) and global country specializations. It is used databases and data sources Ecoinvent; ELCD; LCA Food DK; US LCI; Agri–Footprint LCI database; US Input Output Library; Swiss Input Output Database; and time horizon for the GWP assessment over 20, 100, and 500 years (Peter et al., 2017; Ferrández-García et al., 2016).

SimaPro 8.05 software was used because this calculator was originally developed to evaluate the potential environmental burden of a product during its production, use, disposal and detect mitigation options in the production chain. The estimation of the production chain is also able to extend the system boundary to the end of the life cycle for the assessed production chain by including different direct and indirect GHG emission sources related to the cultivation of the crop (IPCC, 2006).

It was determined the effectiveness of the soil biotreatment for reducing GHGs from soil tillage. The LC was evaluated according to the LST EN ISO 14040:2007 standard for one ton of winter wheat/rapeseed, which was performed by the SimaPro 8.05 software and databases without analysing the same methodologically influential processes. The life cycle inventory (LCI) was built using primary data for energy consumption

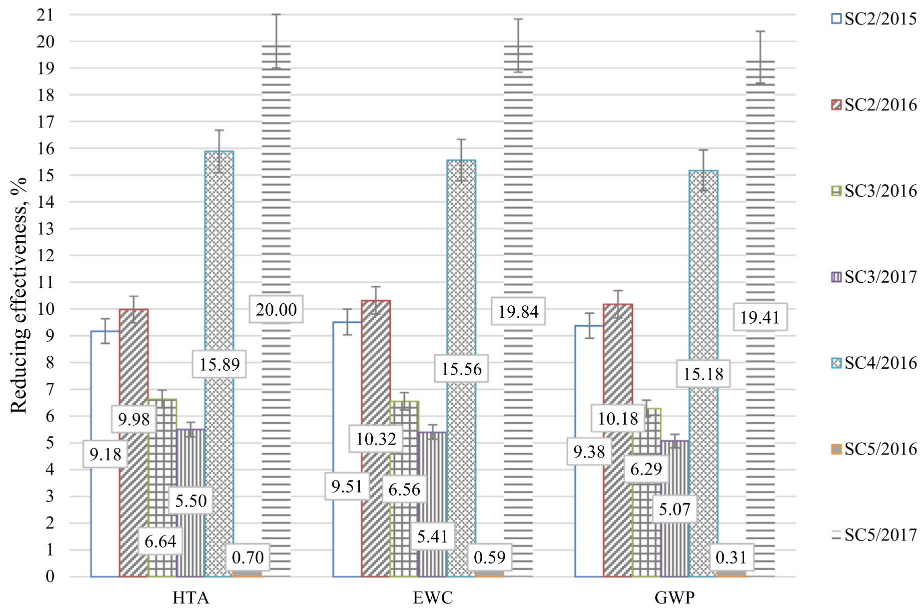

Fig. 3.3. Main impact categories (HTA, EWC and GWP) reducing the dependence on biotreatment compared with the control (C). The assessment of distributed biotreatment is based on the effectiveness of reducing the indicator impact.

studies from 2015 to 2017, with the exception of phases were affected soil biotreatment. Harvest changes were included in FU evaluation. The winter wheat ("Ada", "Famulus") and rapeseed ("Cult") cultivation technologies changed the assessment of the conventional cycle to include a new additional bio–spraying technology. It was done for finding the effect of different bio–solutions with natural compositions.

Emissions were generated from the production, packaging, storage, and transportation (of bio-solutions, herbicides, fungicides, growth regulators, and fertilizers) processes, as well as the use of farm machinery and diesel fuel for different kinds of field operations, including seed cultivation (Beer et al., 2002; Ponsioen and Blonk, 2012; Lal, 2004; Gan et al., 2011; Gan et al., 2012; Berry et al., 2010).

It was measured and assessed fuel consumption for three years in a row. Established that tillage was the main pollution source due to diesel fuel consumption, impact categories and GHGs from the manufacturing of agricultural machinery.

Under advanced technology, disc harrowing and ploughing were carried out during the period from August to September (Fig. 2.2, Table 2.1) to disperse fertilizer before sowing (NPK). Winter wheat (2015 and 2016) and rapeseed (2017) were sown until mid–September, followed by crop spraying 2–3 times during the growing season for pests and diseases from March–May of the following year (e.g., herbicides, growth regulators, fungicides) (Fig. 2.2, Table 2.1) until the harvest was harvested in July and August. The additional step in the winter plant growth technology is soil spraying using different natural bio–solutions (limit: 2–4 L ha^{-1}). Its mixtures were used in the same individual areas in April and May (Fig. 2.2, Table 2.1). The control area was sprayed with water (limit: 200 L ha^{-1}). According to the system boundaries, the process flows were divided into general and individual stages, and a comparative assessment was made using the newly added technology. From the detailed life–cycle assessment plan, evaluating the effectiveness of only using soil biotreatment to reduce the GWP resulted in the rejection of the same methodological and influential agrotechnical processes, and similar cultivation system phases. Which were analysed standard agricultural technology for production and maintenance, field management, such as agrochemical applications and harvest (sorting, pre–cleaning, dehulling drying, cleaning, temporary storage in warehouses, and raw material transport (plant protection measurements)) (Houshyar and Grundmann, 2017; Mousavi-Avval et al., 2017). The GWP (SimaPro EDIP 2003, V1.04 method). Additional data were obtained from national and EU databases, literature, and existing LCI databases (Professional, Ecoinvent v.3.1). The systematically modelled complex identified the production cycle of the supply chain and the most recent impacts of soil biotreatment on different crops under different meteorological conditions.

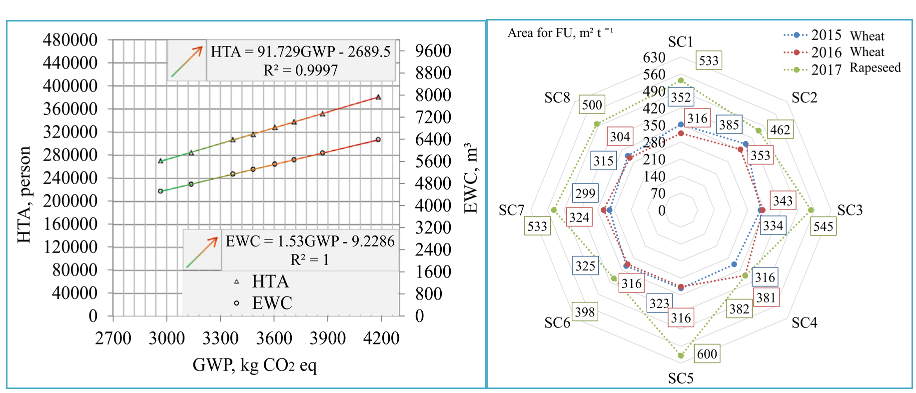

Fig. 3.4. The effectiveness of biotreatment on GWP reducing in different crop rotation.

2.2. Functional unit

The life cycle assessment relative approach (EDIP 2003 V1.04) is based on the functional unit (FU) (LST EN ISO 14044: 2007). FU normalizes the evaluated data. The mass–based FU used in the LCA model to analyse the results of the yields of wheat and rapeseed, its related environmental effects (Houshyar and Grundmann, 2017).

After the detailed life–cycle assessment plan and rejecting equally methodical and influential agrotechnical processes, the mass balance for one functional unit according to the LST EN ISO 14040:2007 standard for one tonne of winter wheat/rapeseed was evaluated (Table 2.2).

Since the selection of FUs can affect environmental performance, this study identifies some of the most important functions of agricultural management (t kg^{-1} for wheat/rapeseed grains and ha^{-1} of cultivated ha m^2 year (m^2 t^{-1}), which could show more fluctuations. Taking into account the fact that the environmental impact of conventional soil tillage was unchanged when the FU was kg ha^{-1} or ha $year^{-1}$. It was decided to analyse one of them (Khasreen et al., 2009; Nebel et al., 2006). According to 2050, the results were converted into CO_2 equivalents using a 100 years period (Ceschia et al., 2010).

2.3. Statistical analysis

Estimated accuracy of research results on average 5% (with a numeric accuracy value of $p < 0.05$). The data for calculating the baseline results using one–factor analysis of the data variance using the Honest Significant Difference Method between the averages of the data evaluation (HSD_{05}) (probability level 95%) (Tukey, 1979).

3. Results and discussion

3.1. Soil biotreatment effectiveness for reducing impact categories from agricultural machinery operations during LCA phase

The total values of the affected impact categories during the main cultivation operations were estimated to be in accordance with the IPCC's tier methodology (IPCC, 2006). One hectare of rotated wheat/wheat/rapeseed croplands was analysed for three years in a row. The same influencing phases, substantiated for specified ranges, were rejected during the implementation of the LCA.

The unbalanced effects of innovative phases from farm machinery operations, such as soil biotreatment, disc harrowing, and ploughing, were analysed exhaustively after establishing these phases as one of the biggest total GHG emissions (Fig. 3.1).

Approximately the same percentage farm machinery operations was established by other scientists. The largest impact ~193 kg CO_2 eq ha^{-1} from ploughing operations, comprised approximately 42 ± 2% of the total and ~129 kg CO_2 eq ha^{-1} derived from disc harrowing operations, which comprised approximately 28 ± 2% of all operations. Other operations, such as sowing, herbicide spraying, harvesting and fertilization, comprised ~32 kg CO_2 eq. (7 ± 1%), ~23 kg CO_2 eq (5 ± 2%), ~64 (14 ± 1%) and ~23 (5 ± 2%), respectively (Gan et al., 2011; Meisterling et al., 2009; Solomon et al., 2007; Alhajj Ali et al., 2017) (Fig. 3.2).

LCA impact categories values depend on soil biotreatment and crop rotation, farm machinery operations, agricultural input, transport and crop fields.

Different scientists found that the total GWP varied within an interval range from approximately 463 to 2789 kg CO_2 eq for cultivated wheat (Alhajj Ali et al., 2017; Fallahpour et al., 2012; Wang et al., 2015) and approximately 707 to 2292 kg CO_2 eq for cultivated rapeseed (Mousavi-Avval et al., 2017). The dependence of soil biotreatment for GHG emissions were evaluated for the field operations of wheat and rapeseed cultivation. Fuel consumption via tillage (L ha^{-1}) was also recalculated to CO_2 emissions to compare dependencies.

3.2. Dependence of variations in the life cycle impact categories on soil biotreatment and crop rotations

Impact category factors were expressed in descending order: human toxicity air, ecotoxicity water chronic, global warming, ecotoxicity water acute, ozone formation, human toxicity water, ecotoxicity soil chronic, human toxicity soil, terrestrial eutrophication and acidification. (Table 3.1). The overall assessment of non-evaluated and zero-level indicators was in the following order: ozone depletion, ozone formation, ozone formation, acidification, terrestrial eutrophication, aquatic eutrophication EP(N), aquatic eutrophication EP(P), human toxicity air,

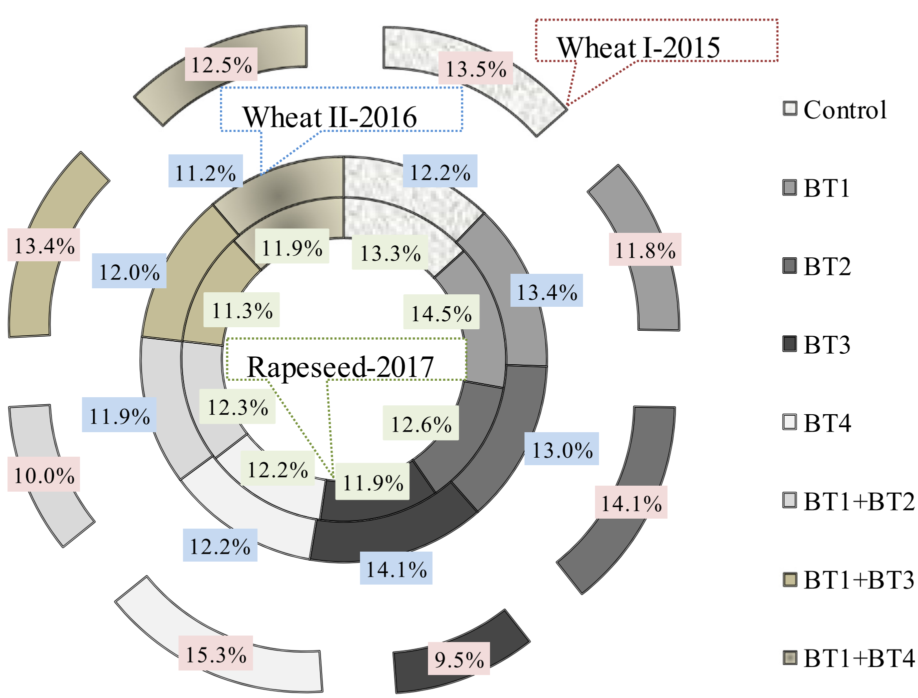

Fig. 3.5. The effectiveness of biotreatment on percentage part of GWP (kg CO_2 eq).

human toxicity water, human toxicity soil, ecotoxicity water chronic, ecotoxicity water acute, ecotoxicity soil chronic, hazardous waste, slags/ashes, bulk waste, and radioactive waste. These categories were separated by maximum numerical value indicators. Excluding only the affected categories within the total indicator summed up in stages such as bio–solutions spraying, disc harrowing and ploughing which were influenced by soil biotreatment (Table 3.1). The first three largest values in categories without normalization HTA, EWC and GWP were identified in the comprehensive analysis.

The impacts of different crops on the effectiveness of soil biotreatment were represented by the LCA impact categories. Integration of different cereal crops could affect the cultivation of winter grains (Brankatschk and Finkbeiner, 2014, Bullock, 1992; Karlen et al., 2013; Munkholm et al., 2013; Berzsenyi et al., 2000; Blanco-Canqui and Lal, 2009). The effects of crop changes on subsequent crops were also established. The crop rotation effect could be analysed by conducting long-term multivariate assessments (Berzsenyi et al., 2000; Karlen et al., 2013; Blanco-Canqui and Lal, 2009).

The greatest effect of biotreatment (BT4) for reducing impact was approximately 19–20% HTA; EWC and GWP in 2017 compared with the control. The impact categories reduced by 15–16% when comparing BT3 with the control in 2016. 9–11% when comparing BT1 with the control in 2015 and 2016. Comparing BT2 with the control resulted in a reduction of approximately 5–7% for impact categories in 2016 and 2017 (Fig. 3.3).

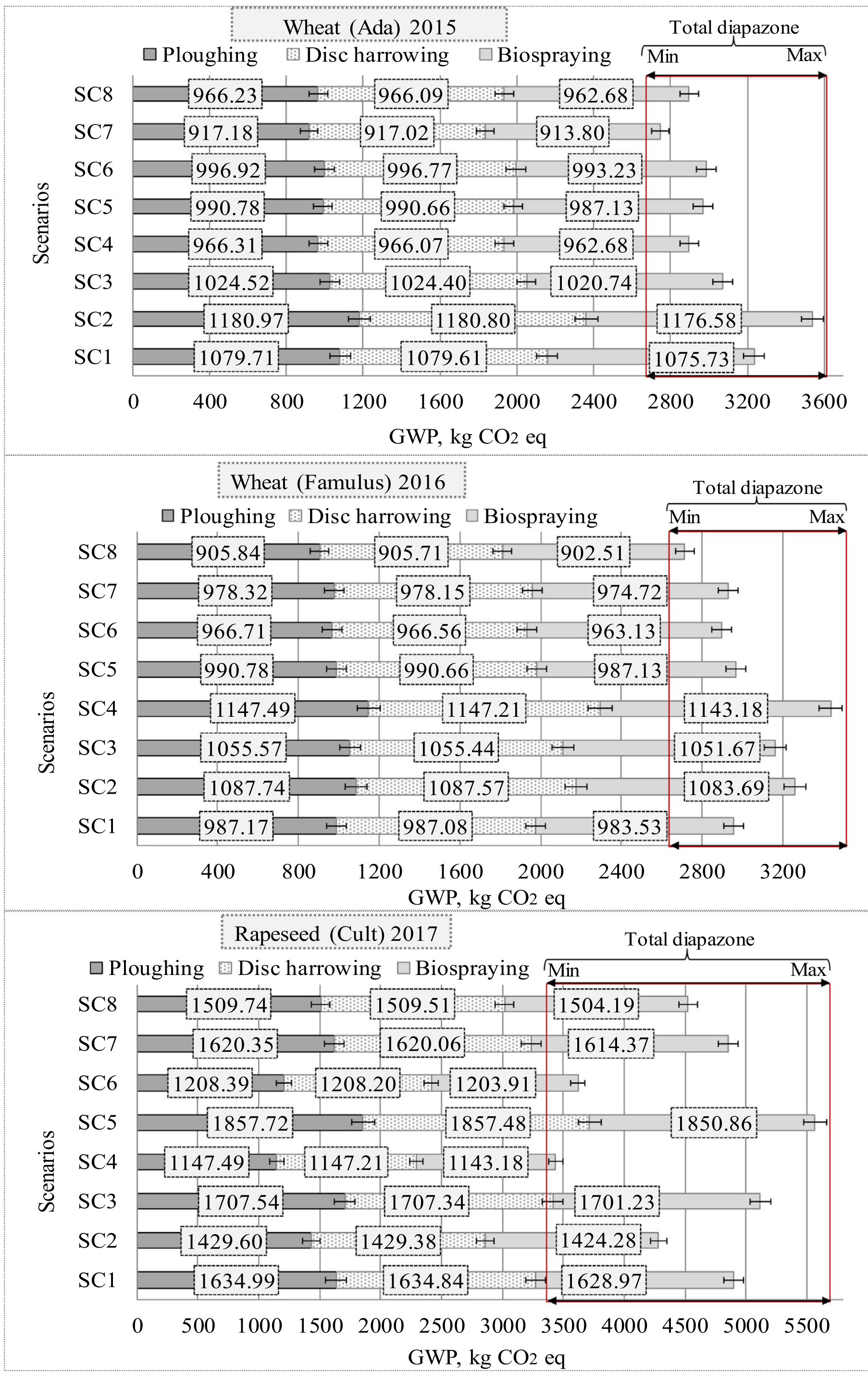

Fig. 3.6. GWP dependence on biospraying, disc harrowing and ploughing soil tillage after different soil biotreatment.

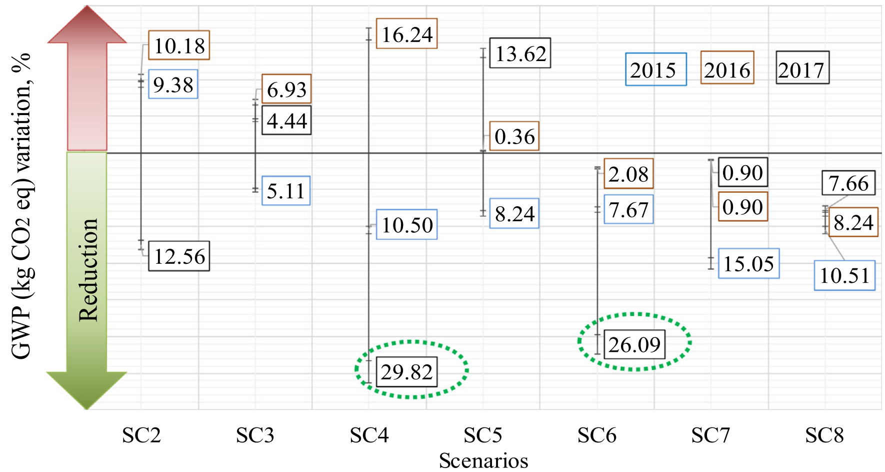

Fig. 3.7. GWP percentage reduction dependence on biotreatment effectiveness comparing with control.

The correlation analysis provides a strong linear statistical relationship between the HTA and GWP and a very strong linear statistical relationship between the EWC and GWP. The GWP increases with HTA and EWC according to a fixed FU.for three different years (Fig. 3.4).

In accordance with recommendations of the ISO standards on the LCA and the default lists (Sleeswijk et al., 2008; Stranddorf et al., 2003), the choice of impact categories based on avoiding the double counting of defined exposure classes. The purpose of substance validity is further elaborated by the GWP, which reflects the comprehensive environmental issue.

Other scientific studies are based on the need to reduce environmental pollution from conventional tillage systems. It has been highlighted that no–tillage and reduced-tillage systems can achieve better environmental performance than conventional tillage systems and have the lowest impact on the GWP and other environmental categories (Houshyar and Grundmann, 2017; Fallahpour et al., 2012; Lovarelli et al., 2017). It is a relevant analysis for crop rotation, as it affects the environmental performances of crops and products.

3.3. GWP reduction dependence on different soil biotreatment

After evaluating the interactions the average percentage of operations corresponded to the different bioavailability each year via the growth and rotation of wheat and rapeseed (Fig. 3.5).

The percent variance in the GWP was influenced by various treatments and interactions. The main percentages of all fixed GWP in 2015 contained the BT4, control and BT2 biotreatment. Which varied from 13.5% to 15.3%. In 2016 and 2017, the second and third biotreatments had lower component values, which varied from 11.2% to 14.5%. In addition, the highest efficiency and lowest percentages were determined based on the bio–effect during all research years for different crop growth and meteorological conditions, but not for the same biotreatment variants. Therefore, detailed analysis was performed.

Other scientists assessed different effects from 839 to 2099 kg CO_2 eq ha^{-1} for different treatment rates on GHGs in different tillage systems, and the highest emissions were found using primary tillage in conventional tillage systems, and the second highest emissions were found using secondary tillage in conventional tillage systems (Lal, 2004; Reeves, 1997; Smith et al., 1998).

Different soil biotreatment were estimated for the functional unit (Fig. 3.6). The measurement of wheat/rapeseed grain (kg (t) ha^{-1}) was the main FU (in cultivated hectares per year), which is useful regarding the impacts of agriculture and corresponding environmental tillage systems and does not change if the FU is kg ha^{-1} or ha year^{-1}.

The largest GWP changes fixed approximately 15% in the mixed variant (BT1 and BT3) in 2015. 8% was in the mixed variant (BT1 and BT4) in 2016 and approximately 30% in BT3 in 2017 compared to the control. Significant changes in CO_2 emissions from ploughing were found comparing different biotreatment in 2015 and 2016. It had the same trend as for disc harrowing. The obvious change was due to the change in crop, from wheat to rapeseed, after the third soil treatment in 2017. The amount of carbon dioxide from ploughing varied from 917.2 to 1181 kg CO_2 eq in 2015. Also from 905 to 1147 kg CO_2 eq in 2016. The amount of carbon dioxide was significantly higher in 2017 from 1147 to 1858 kg CO_2 eq, which was due to the maximum third soil treatment and crop rotation in 2017 (Fig. 3.7).

It was assessed that the GWP maximum reductions up to 15% in 2015 (BT1 and BT3), 8% in 2016 (BT1 and BT4) and 30% in 2017 (BT3) compared with the control. The total GWP is a crucial factor, in which variations can also be addressed for other GHG changes and dependencies. LCA estimation based on input parameters received using the SimaPro software and the apparent significant differences in 2017 were due to the parameters, which depend on each other. The FU depends on the yield, and the GWP depends on the FU (Fig. 3.8).

In the correlation analysis for each pair of variables (T–FU, H–FU, and TH), it was determined that the total variables (GWP and FU) had the same tendency. Positive correlations and large values for one variable can be associated with large values of the other variable for wheat cultivation. The total GWP and FU values did not tend to be correlated (correlation was close to zero) during rapeseed cultivation. The assessed negative correlation of the H variable can be associated with large values of the FU during wheat and rapeseed cultivation and combined with total GWP values during wheat cultivation.

Other scientists show that possibilities for GHG reduction could be achieved with a balanced increase in green fertilizers and the efficiency of use (Singh et al., 2016). Also by reducing fuel consumption from the optimization of agricultural technological processes (Janulevičius and Damanauskas, 2015; Moitzi et al., 2013; Kheiralla et al., 2004). Other variants to reduce GHG emissions could be mechanized and adopted by irrigation systems, accurate fertilization management, and crop residues using as energy sources (Mohammadi et al., 2014). In addition, the main crops during the period of grazing and unused nutrients can be integrated into the biological metabolism circle, and intermediate crops are accumulated in the biomass and roots of the nutrients that became plant nutrition products (Bučienė et al., 2003; Arlauskienė and Maikštėnienė, 2007). Tillage could depend on differences in terms of depth, fuel consumption, type of machine used and high GHG emissions due to fuel consumption during tillage and different levels of soil disturbance, which vary in terms of their ability to sequester C (Reeves, 1997; Smith et al., 1998; Lal, 2004). Scientists have also established that intercropping with concrete herbs (I. indigotica) can significantly decrease CO_2 emissions from soil under wheat cultivation (Wu et al., 2017).

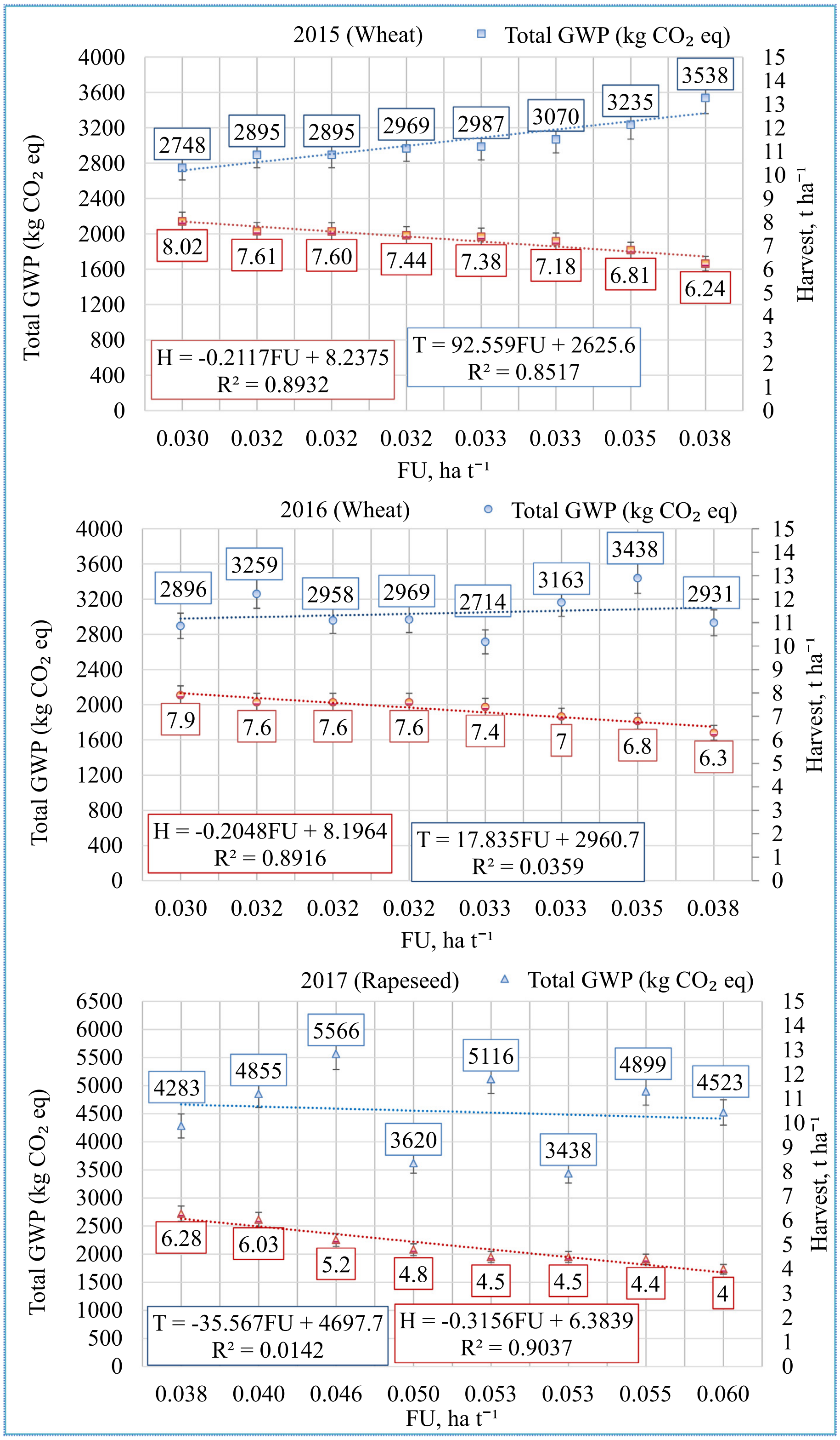

Fig. 3.8. Total (T) GWP (soil biospraying, disc harrowing, ploughing), FU and harvest (H) interdependence.

After discovering the effectiveness of certain biotreatment for specialized use, the possibility of activated microbiological processes in soil has been discovered. Where changes in the interaction between the working parts of soil and machinery, decreases in soil resistance, reductions in fuel and energy consumption, and after–life cycle assessment resulted in major impact categories GHG emissions.

4. Conclusions

1. The results of the whole life cycle phase assessment proved that the largest bio-treatment effect on reduction of human toxicity and ecotoxicity due to chronic air and water pollution as well as global warming potential from farm machinery operations was

approximately 19–20% after the third soil bio-treatment. Compared to the control variant, after the first and second soil bio-treatments, the impact categories reduced by approximately 9–11% and 15–16%, respectively.

2. The correlation analysis identified strong and very strong linear statistical relationships respectively with regard to predictions of human toxicity and ecotoxicity due to chronic air and water pollution, which decreased with the corresponding reduction in global warming potential.
3. After confirming that disc harrowing and soil ploughing account for 26% and 40% respectively of all farm machinery operations, conventional tillage was found to be the largest contributor to total emissions.
4. Analysis of the percentage effectiveness of different bio-treatments in reducing equivalent CO_2 emissions established that 86%, 43%, and 71% of reductions were achieved after the first, second, and third bio-treatments, respectively.
5. The maximum reduction in equivalent CO_2 emissions was attributed to disc harrowing and fixed ploughing for approximately 15% of mixed variants (bacterial and non-bacterial) after the first year, 8% of mixed variants (bacterial and non-bacterial) after the second year, and 30% of the variants (bacterial) after the third year compared to the control. Emissions from ploughing varied from 917.2 to 1181 kg of equivalent CO_2 emissions after the first year, and from 905 to 1147 kg of equivalent CO_2 emissions after the second year. The emissions were significantly higher in the third year (1147 to 1858 kg CO_2eq) because the maximum number of soil treatments (three) and crop rotation were implemented in the third year.
6. It is recommended that conducting soil treatment with bio-solutions in spring (when a robust plant growth cycle is restored) could decrease the global warming potential from post-harvest soil tillage. The application of an innovative crop production method can contribute to the implementation and continued development of the EU's environmental and climate policies and legislations, which would create added value for Europe. The economic assessment of the proposed method will be conducted in a future study.

References

Alhajj Ali, S., Tedone, L., Verdini, L., Mastro, G., 2017. Effect of different crop management systems on rainfed durum wheat greenhouse gas emissions and carbon footprint under Mediterranean conditions. J. Clean. Prod. 140 (Part 2), 608–621. https://doi.org/10.1016/j.jclepro.2016.04.135.

Arlauskienė, A., Maikštėnienė, S., 2007. The effect of legume plants as a pre-duct on the nitrogen circulation cycle in the crop rotational chain. Agriculture 94 (3), 100–112.

Bartzas, G., Vamvuka, D., Komnitsas, K., 2017. Comparative life cycle assessment of pistachio, almond and apple production. Inf. Process. Agric. 4 (3), 188–198. https://doi.org/10.1016/j.inpa.2017.04.001.

Beer, T., Grant, T., Williams, D., Watson, H., 2002. Fuel-cycle greenhouse gas emissions from alternative fuels in Australian heavy vehicles. Atmos. Environ. 36 (4), 753–763.

Berry, P.M., Spink, J., Foulkes, M.J., White, P.J., 2010. The physiological basis of genotypic differences in nitrogen use efficiency in oilseed rape (*Brassica napus* L.). Field Crop Res. 119 (2–3), 365–373. https://doi.org/10.1016/j.fcr.2010.08.004.

Berzsenyi, Z., Győrffy, B., Lap, D., 2000. Effect of crop rotation and fertilisation on maize and wheat yields and yield stability in a long-term experiment. Eur. J. Agron. 13 (2–3), 225–244. https://doi.org/10.1016/S1161-0301(00)00076-9.

Blanco-Canqui, H., Lal, R., 2009. Crop residue removal impacts on soil productivity and environmental quality. Crit. Rev. Plant Sci. 28, 139–163.

Bos, H., Meesters, K., 2008. Sustainability evaluation of high value-added products. LNV Project O-03-007-008/Agrotechnology and Food Inno-vations, Wageningen UR. 29.

Brankatschk, G., Finkbeiner, M., 2014. Application of the Cereal Unit in a new allocation procedure for agricultural life cycle assessments. J. Clean. Prod. 73, 72–79.

Bullock, D.G., 1992. Crop rotation. Crit. Rev. Plant Sci. 11, 309–326.

Ceschia, E., Béziat, P., Dejoux, J.F., Aubinet, M., Bernhofer, Ch., Bodson, B., Buchmann, N., Carrara, A., Cellier, P., Di Tommasi, P., Elbers, J.A., Eugster, W., Grünwald, T., Jacobs, C.M.J., Jans, W.W.P., Jones, M., Kutsch, W., Lanigan, G., Wattenbach, M., 2010. Management effects on net ecosystem carbon and GHG budgets at European crop sites. Agric. Ecosyst. Environ. 139 (3), 363–383. https://doi.org/10.1016/j.agee.2010.09.020.

Cesevičius, G., Janušauskaitė, D., 2006. Microbiological and physical properties of soils in different soil tillage systems. Zemdirbyste-Agriculture 93 (3), 18–34 (In Lithuanian).

Chaudhary, V.P., Gangwar, B., Pandey, D.K., 2006. Auditing of energy use and output of different cropping systems in India. Agric. Eng. Int. CIGR J. 1–13.

Elhami, B., Akram, A., Khanali, M., 2016. Optimization of energy consumption and environmental impacts of chickpea production using data envelopment analysis (DEA) and multi objective genetic algorithm (MOGA) approaches. Inf. Process. Agric. 3 (3), 190–205. https://doi.org/10.1016/j.inpa.2016.07.002.

Epron, D., Plain, C., Ndiaye, K., Bonnaud, P., Pasquier, C., Ranger, J., 2016. Effects of compaction by heavy machine traffic on soil fluxes of methane and carbon dioxide in a temperate broadleaved forest. For. Ecol. Manag. 382, 1–9. https://doi.org/10.1016/j.foreco.2016.09.037.

Fallahpour, F., Aminghafouri, A., Ghalegolab, Behbahani A., Bannayan, M., 2012. The environmental impact assessment of wheat and barley production by using life cycle assessment (LCA) methodology. Environ. Dev. Sustain. 14 (6), 979–992.

Fernández-Tirado, F., Parra-López, C., Romero-Gámez, M., 2016. Life cycle assessment of biodiesel in Spain: comparing the environmental sustainability of Spanish production versus Argentinean imports. Energy Sustain. Dev. 33, 36–52. https://doi.org/10.1016/j.esd.2016.04.005.

Ferrández-García, A., Ibáñez-Forés, V., Bovea, M.D., 2016. Eco-efficiency analysis of the life cycle of interior partition walls: a comparison of alternative solutions. J. Clean. Prod. 112 (Part 1), 649–665. https://doi.org/10.1016/j.jclepro.2015.07.136.

Gabain, R.G., 2007. Manager of Stetchworth Estate, Cambridgeshire, UK (Private communication).

Gan, Y.T., Liang, C., Hamel, C., Cutforth, H.W., Wang, H., 2011. Strategies for reducing the carbon footprint of field crops for semiarid areas. A review. Agron. Sustain. Dev. 31 (4), 643–656.

Gan, J., Smith, C.T., Langeveld, W.A., 2012. Effects of considering greenhouse gas consequences on fertilizer use in loblolly pine plantations. J. Environ. Manag. 113, 383–389. https://doi.org/10.1016/j.jenvman.2012.09.015.

Goglio, P., Smith, W.N., Grant, B.B., Desjardins, R.L., Gaoc, X., Hanis, K., Tenuta, M., Campbell, C.A., McConkey, B.G., Nemecek, T., Burgess, P.J., Williams, A.G., 2018. A comparison of methods to quantify greenhouse gas emissions of cropping systems in LCA. J. Clean. Prod. 172, 4010–4017. https://doi.org/10.1016/j.jclepro.2017.03.133.

Gong, X., Huang, D., Liu, Y., Zeng, G., Wang, R., Wan, J., Zhang, C., Cheng, M., Qin, X., Xue, W., 2017. Stabilized nanoscale zerovalent iron mediated cadmium accumulation and oxidative damage of Boehmeria nivea (L.) Gaudich cultivated in cadmium contaminated sediments. College of Environmental Science and Engineering, Hunan University, Changsha 410082, China. Environ. Sci. Technol. 51 (19), 11308–11316. https://doi.org/10.1021/acs.est.7b03164.

Herrmann, I.T., Moltesen, A., 2015. Does it matter which Life Cycle Assessment (LCA) tool you choose? – a comparative assessment of SimaPro and GaBi. J. Clean. Prod. 86, 163–169. https://doi.org/10.1016/j.jclepro.2014.08.004.

Houshyar, E., Grundmann, P., March 2017. Environmental impacts of energy use in wheat tillage systems: a comparative life cycle assessment (LCA) study in Iran. Energy 122 (1), 11–24. https://doi.org/10.1016/j.energy.2017.01.069.

Huang, D., Deng, R., Wan, J., Zeng, G., Xue, W., Wen, X., Zhou, C., Hu, L., Liu, X., Xu, P., Guo, X., Ren, X., 2018. Remediation of lead-contaminated sediment by biochar-supported nano-chlorapatite: accompanied with the change of available phosphorus and organic matters. J. Hazard. Mater. 348, 109–116. https://doi.org/10.1016/j.jhazmat.2018.01.024.

Ingrao, C., Licciardello, F., Pecorino, B., Muratore, G., Zerboc, A., Messineo, A., January 2018. Energy and environmental assessment of a traditional durum-wheat bread. J. Clean. Prod. 171 (10), 1494–1509. https://doi.org/10.1016/j.jclepro.2017.09.283.

IPCC, 2006. Guidelines for National Greenhouse Gas Inventories, Agriculture, Forestry and Other Land Use, 4, Prepared by the National Greenhouse Gas Inventories Programme, Hayama, Japan.

Janulevičius, A., Damanauskas, V., 2015. How to select air pressures in the tires of MFWD (mechanical front-wheel drive) tractor to minimize fuel consumption for the case of reasonable wheel slip. Energy 90 (Part 1), 691–700. https://doi.org/10.1016/j.energy.2015.07.099.

Kaltschmitt, M., Reinhardt, G.A., Stelzer, T., 1997. Life cycle analysis of biofuels under different environmental aspects. Biomass Bioenergy 12 (2), 121–134.

Karlen, D.L., Cambardella, C.A., Kovar, J.L., Colvin, T.S., 2013. Soil quality response to long-term tillage and crop rotation practices. Soil Tillage Res. 133, 54–64. https://doi.org/10.1016/j.still.2013.05.013.

Khasreen, M.M., Banfill, P.F.G., Menzies, G.F., 2009. Life-cycle assessment and the environmental impact of buildings: a review. Sustainability (1), 674–701 https://doi.org/10.3390/su1030674 (ISSN 2071-1050).

Kheiralla, A.F., Yahya, A., Zohadie, M., Ishak, W., 2004. Modelling of power and energy requirements for tillage implements operating in Serdang sandy clay loam, Malaysia. Soil Tillage Res. 78 (1), 21–34. https://doi.org/10.1016/j.still.2003.12.011.

Kole, C., 2006. Cereals and millets. MJA, 2015. Annual Agricultural Statistics. Ministry of Jihad-e-Agriculture of Iran. Springer, Berlin, New York www.maj.ir.

Lal, R., 2004. Soil carbon sequestration to mitigate climate change. Geoderma 123 (1–2), 1–22. https://doi.org/10.1016/j.geoderma.2004.01.032.

Lovarelli, D., Bacenetti, J., Fiala, M., 2017. Effect of local conditions and machinery characteristics on the environmental impacts of primary soil tillage. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2016.02.011.

Mani, I., Kumar, P., Panwar, J.S., Kant, K., 2007. Variation in energy consumption in production of wheat-maize with varying altitudes in hilly regions of Himachal Pradesh, India. Energy 32, 2336–2339.

Mažvila, J., Vaičys, M., Buivydaitė, V.V., 2006. Macromorphological diagnostics of Lithuanian soils. Lietuvos dirvožemių makromorfologinė diagnostika. 2006. Akademija (283 p., In Lithuanian).

Meisterling, K., Samaras, C., Schweizer, V., 2009. Decision to reduce greenhouse gases from agriculture and product transport: LCA case study of organic and conventional wheat. J. Clean. Prod. 17, 222–230.

Mohammadi, A., Rafiee, S., Jafari, A., Keyhani, A., Mousavi-Avval, S.H., Nonhebel, S., 2014. Energy use efficiency and greenhouse gas emissions of farming systems in north Iran. Renew. Sust. Energ. Rev. 30, 724–733. https://doi.org/10.1016/j.rser.2013.11.012.

Moitzi, G., Haas, M., Wagentristl, M., Boxberger, J., Gronauer, A., 2013. Energy consumption in cultivating and ploughing with traction improvement system and consideration of

the rear furrow wheel-load in ploughing. Soil Tillage Res. 134, 56–60. https://doi.org/10.1016/j.still.2013.07.006.

Mortimer, N.D., Elsayed, M.A., 2006. North East Biofuel Supply Chain Carbon Intensity Assessment. North Energy Associates Ltd.

Mousavi-Avval, S.H., Rafiee, S., Sharifi, M., Hosseinpour, S., Notarnicola, B., Tassielli, G., Renzulli, P.A., Khanali, M., September 2017. Use of LCA indicators to assess Iranian rapeseed production systems with different residue management practices. Ecol. Indic. 80, 31–39. https://doi.org/10.1016/j.ecolind.2017.04.045.

Munkholm, L.J., Heck, R.J., Deen, B., 2013. Long-term rotation and tillage effects on soil structure and crop yield. Soil Tillage Res. 127, 85–91.

Naujokienė, V., Šarauskis, E., Lekavičienė, K., Adamavičienė, A., Buragienė, S., Kriaučiūnienė, Z., June 2018. The influence of biotreatment on the reduction of energy consumption and CO_2 emissions in shallow and deep soil tillage. Sci. Total Environ. 626 (1), 1402–1413. https://doi.org/10.1016/j.scitotenv.2018.01.190.

Nebel, B., Zimmer, B., Wegener, G., 2006. Life cycle assessment of wood floor coverings a representative study for the German Flooring Industry. Int. J. Life Cycle Assess. 11, 172–182.

Nix, J., 2007. Typical contractors' charges, average farmers' costs, and rates of work for various farm operation. Farm Management Pocketbook, 37th edn. The Andersons Centre, UK, pp. 156–162.

Notarnicola, B., Salab, S., Antonc, A., McLarend, S.J., Saouterb, E., Sonessone, U., 2017. The role of life cycle assessment in supporting sustainable agri-food systems: a review of the challenges. J. Clean. Prod. 140 (Part 2), 399–409. https://doi.org/10.1016/j.jclepro.2016.06.071.

Peter, C., Helming, K., Nendel, C., January 2017. Do greenhouse gas emission calculations from energy crop cultivation reflect actual agricultural management practices? – a review of carbon footprint calculators. Renew. Sust. Energ. Rev. 67, 461–476. https://doi.org/10.1016/j.rser.2016.09.059.

Ponsioen, T.C., Blonk, T.J., 2012. Calculating land use change in carbon footprints of agricultural products as an impact of current land use. J. Clean. Prod. 28, 120–126. https://doi.org/10.1016/j.jclepro.2011.10.014.

Reeves, D.W., 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil Tillage Res. 43 (1–2), 131–167. https://doi.org/10.1016/S0167-1987(97)00038-X.

Robertson, G.P., Paul, E.A., Harwood, R.R., 2000. Greenhouse gases in intensive agriculture: contributions of individual gases to the radiative forcing of the atmosphere. Science 289, 1922–1925.

Singh, P., Kansal, A., Carliell-Marquetc, C., 2016. Energy and carbon footprints of sewage treatment methods. J. Environ. Manag. 165, 22–30. https://doi.org/10.1016/j.jenvman.2015.09.017.

Sleeswijk, A.W., Oers, L.F.C.M., Guinée, J.B., Struijs, J., Huijbregts, M.A.J., 2008. Normalisation in product life cycle assessment: an LCA of the global and European economic systems in the year 2000. Sci. Total Environ. 390 (1), 227–240. https://doi.org/10.1016/j.scitotenv.2007.09.040.

Smith, S.R., Woods, V., Evans, T.D., 1998. Nitrate dynamics in biosolids-treated soils. I. Influence of biosolids type and soil type. Bioresour. Technol. 66 (2), 139–149. https://doi.org/10.1016/S0960-8524(97)00095-3.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L., 2007. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 996.

Stephenson, A.L., Dennis, J.S., Scott, S.A., 2008. Improving the sustainability of the production of biodiesel from oilseed rape in the UK. Process. Saf. Environ. Prot. 86 (6), 427–440. https://doi.org/10.1016/j.psep.2008.06.005.

Stranddorf, H.K., Hoffmann, L., Schmidt, A., Environmental Protection Agency. Serietitel, 2003. LCA Technical Report: Impact Categories, Normalisation and Weighting in LCA. Update on Selected EDIP97-Data FORCE Technology/dk-TEKNIK.

Švedas, A., Tripolskaja, L., Plesevičienė, A., Janušienė, V., 2001. The Influence of Fertilizers on Soil Agrochemical Properties. Lithuanian Soils (Trąšų įtaka dirvos agrocheminėms savybėms. Lietuvos dirvožemiai). 2001 pp. 960–971 (In Lithuanian).

Thamsiriroj, T., Murphy, L.D., 2009. Is it better to import palm oil from Thailand to produce biodiesel in Ireland than to produce biodiesel from indigenous Irish rape seed? Appl. Energy 86 (5), 595–604. https://doi.org/10.1016/j.apenergy.2008.07.010.

Todorović, M., Mehmeti, A., Cantore, V., May 2018. Impact of different water and nitrogen inputs on the eco-efficiency of durum wheat cultivation in Mediterranean environments. J. Clean. Prod. 183 (10), 1276–1288. https://doi.org/10.1016/j.jclepro.2018.02.200.

Tukey, J.W., 1979. Robust techniques for the user. Robustness Stat., 103–106 https://doi.org/10.1016/B978-0-12-438150-6.50013-3.

Tullberg, J., Antille, D.L., Bluett, C., Eberhard, J., Scheer, C., 2018. Controlled traffic farming effects on soil emissions of nitrous oxide and methane. Soil Tillage Res. 176, 18–25. https://doi.org/10.1016/j.still.2017.09.014.

Van Stappen, F., Loriers, A., Mathot, M., Planchon, V., Stilmant, D., Debode, F., 2015. Organic versus conventional farming: the case of wheat production in Wallonia (Belgium). Agric. Agric. Sci. Procedia 7, 272–279. https://doi.org/10.1016/j.aaspro.2015.12.047.

Wang, J., Yang, Y., Mao, T., Sui, J., Jin, H., 2015. Life cycle assessment (LCA) optimization of solar-assisted hybrid CCHP system. Appl. Energy 146, 38–52. https://doi.org/10.1016/j.apenergy.2015.02.056.

Wang, Z., Zhang, H., Lua, X., Wang, M., Chua, Q., Wen, X., Chen, F., 2016. Lowering carbon footprint of winter wheat by improving management practices in North China Plain. J. Clean. Prod. 112 (Part 1), 149–157. https://doi.org/10.1016/j.jclepro.2015.06.084.

Weinheimer, J., Rajan, N., Johnson, P., Maas, S., 2010. Carbon Footprint: A New Farm Management Consideration in the Southern High Plains. Agricultural and Applied Economics Association 2010, AAEA, CAES and WAEA Joint Annual Meeting, Denver, Colorado, pp. 25–27.

Wu, H.S., Chen, S.Y., Li, J., Liu, D.Y., Zhou, J., Xu, Y., Shang, X.X., Wei, D., Yu, L., Fang, X., Li, S., Wang, K., 2017. An approach to mitigating soil CO_2 emission by biochemically inhibiting cellulolytic microbial populations through mediation via the medicinal herb Isatis indigotica. Atmos. Environ. 158, 259–269. https://doi.org/10.1016/j.atmosenv.2017.03.046.

Xue, W., Peng, Z., Huang, D., Zeng, G., Wan, J., Xu, R., Cheng, M., Zhang, C., Jiang, D., Hu, Z., 2018. Nanoremediation of cadmium contaminated river sediments: microbial response and organic carbon changes. J. Hazard. Mater. 359, 290–299. https://doi.org/10.1016/j.jhazmat.2018.07.062.

Zhang, H., Wang, X., Feng, Z., Pang, J., Lu, F., Ouyang, Z., Zheng, H., Liu, W., Hui, D., 2011. Soil temperature and moisture sensitivities of soil CO_2 efflux before and after tillage in a wheat field of Loess Plateau, China. J. Environ. Sci. 23 (1), 79–86. https://doi.org/10.1016/S1001-0742(10)60376-2.